Description

MRI MAGNET DEVICE WITH AXIALLY ADJUSTABLE ROSE SHIM RING

(1) Technical field

The present invention relates to a method of adjusting the static magnetic field in the magnetic resonance imaging (MRI) device or Nuclear Magnetic Resonance (NMR) device and a static magnetic field generating apparatus that could generate higher field strength. The principle of the present invention will be illustrated by taking a C-type magnet in the magnetic resonance imaging equipment as an example, but the present invention is not only applicable to magnetic resonance magnet, but also to nuclear magnetic resonance magnet and other devices using electro-magnet to generate uniform static magnetic field and the shape of the magnet is also not limited to the exemplified C-type.

(2) Background Art

In the early days when the permanent magnet is used in magnetic resonance imaging equipment for commercial use, the field strength of the permanent magnet was usually lower than 0.25T. In the 1990's, magnetic resonance imaging equipment for commercial use that employ permanent magnet appeared with field strength of 0.3T and the performance thereof was better, the cost was reasonable and the structure was compact. The greater the field strength is, the higher the signal-to-noise ratio is, and better the quality of the image generated by the permanent magnet magnetic resonance equipment. In recent years, the field strength of some of the permanent magnets could even reach 0.35T-0.4T.

At present, some problems exist in the manufacturing of magnet with higher field strength, they are:

I. Permanent magnets having a field strength greater than 0.3T and with high homogeneous magnetic field in the scanning area are expensive, large in volume and heavy in weight (heavier than 17 tons) and need a large area for installation, thus these defects limited its application in the magnetic resonance equipment.

II. Since a uniform strong magnetic field is to be generated, the size of the pole plates are usually large, thus the open angle between the two pole plates will inevitably be limited and this is a problem for patients of claustrophobia.

III. The magnet needs shimming or repairing during its installation and use, or re-shimming is required when service and thus the gradient coil and transmitting coil have to be removed, which is time-consuming and expensive.

IV. Due to manufacturing tolerances, magnets of the same design may have different field strength, thus volume production of the same RF coils and the systems become very difficult and thereby the costs for the corresponding system of the whole magnetic resonance equipment increase.

With respect to the above problems, the following methods are usually employed:

I. In order to increase the field strength and improve the uniformity thereof, the method generally adopted is to increase the volume and size of both the permanent magnet and the pole plate, which will increase the cost as well as the volume and weight of the magnet.

II. The uniformity of the magnetic field is improved by employing a Rose ring but when the field strength is over 0.3T, the magnetic field uniformity of the permanent ~~magnet used for the magnetic resonance~~ of the whole

human body becomes worse and single Rose ring cannot ensure the uniformity of the field strength.

III. Permanent magnets that could reduce magnetic flux leakage are employed to compensate for the field strength leakage in the external edge of the pole plate but said method increases the size of the external edge of the magnet pole plate and reduces the open angle between the pole plates, and meanwhile, it requires complicated manufacturing process and hence increases the cost.

IV. Field strength adjusting and fine adjusting structures are employed, but these mechanisms are complex in designs and expensive.

Moreover, the effects achieved by all these methods in the prior art are still not satisfactory.

(3) Contents of the invention

Therefore, the method and apparatus in the present invention adopts the following measures to overcome the technical defects existing in the prior art.

I. Employing another adjusting shimming ring (the second type of Rose ring) without increasing the size of the pole plate to improve the uniformity of the magnetic field while not reducing the open angle between the pole plates. Meanwhile, said additional shimming ring (the second type of Rose ring) has a variable distance with respect to the first type of Rose ring so as to change the magnetic path and adjust the uniformity of the magnetic field.

II. Distribute permanent magnetic materials having different magnetic energy levels in special manners so as to improve the uniformity of the magnetic field and reduce the cost.

III. Three methods are employed in the present invention to adjust the magnetic field strength and shimming. One is adjusting and shimming the static magnetic field by fine

adjusting magnetic conducting bars or permanent magnetic bars installed on the external edge of the pole plate for example of the C-type magnet, so as to compensate for the inhomogeneous magnetic field caused by tolerances of magnet manufacturing and assembling; another is providing a magnetic conducting or permanent magnet bolt adjusting mechanism on the shimming Rose ring, and the magnetic path is changed by adjusting the position of the bolt so as to adjust the magnetic field; the other method is changing the magnetic path by changing the position of the second type of shimming ring with respect to the first type of Rose ring as mentioned in method one, and thereby to adjust the magnetic field. The joint application of said three methods will achieve a large range of adjustment and is easy in operation. Hence, the inhomogeneity caused by the tolerances of manufacturing and assembling is compensated and the field strength of the permanent magnet is made uniform.

Further, the method and apparatus of the present invention use the above-mentioned two or three methods jointly to achieve better shimming effect.

In the prior art, the Rose shimming ring (5) is provided at the external edges on the horizontal plane of the pole plates of both the upper and lower poles, but the shimming effect achieved by a single pair of shimming rings is not satisfactory. Due to the characteristics of the structure of the permanent magnet, the magnetic field strength at the edge of the pole plate is relatively weak, which is especially serious when the field strength is over 0.3T, thus single shimming ring cannot fully compensate the inhomogeneity of the magnetic field. The present invention improves the design and fixing manner of the gradient coil and the transmitting coil. Taking the upper pole plate shimming ring as an example, an additional shimming ring (the second type of Rose ring) (6) with adjustable distance to the shimming ring (5) is

employed at the external edge of the lower end of the first shimming ring (5) to change the uniformity of the magnetic field and a corresponding shimming adjusting mechanism is provided. Similarly, the second type of shimming ring (6) whose distance with to the first shimming Rose ring (5) is adjustable is also employed at the corresponding position on the lower pole plate.

With respect to the defects in the prior art, the present invention provides a static magnetic field generating apparatus in the magnetic resonance equipment; it comprises permanent magnetic source (1), C-type yoke or a multi-posts supporting structure that constitutes the magnetic path. The measured body is positioned in the space between the two opposite end faces of the permanent magnetic source (1), wherein the said two opposite end faces are mirror symmetrical by the virtual plane between the two faces; Pole plates (2) are placed on each of the opposite end faces. The structure is symmetrical with respect to the virtual middle plane but for the illustration purpose, take the upper half for example, pole pieces (4) are employed beneath the aforementioned pole plate, a gradient coil is employed beneath pole piece (4), an RF transmitting coil (8) is employed beneath gradient coil (7), a first shimming ring (5) is employed outside the gradient coil (7); each pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces. An additional second shimming ring (6) is employed on the external edge of the each of the first shimming rings (5), and the second shimming ring (6) is symmetrical to the above virtual plane, to uniform the static magnetic field in the space of the measured body

According to the static magnetic field generating apparatus of the present invention, the outer faces of the additional

upper and lower shimming rings (6) which are facing the measured body are essentially not projecting higher than the outer plane of the RF transmitting coils to keep the openness of the magnet.

Another solution for the static magnetic field generating apparatus of the present invention is that said magnetic source is composed of a plural groups of permanent magnetic columns of different magnetic energy levels, the distribution of magnetic energy level of columns can be axially symmetric with respect to the central axis through the pole center but perpendicular to the pole plane. The distribution of energy level of columns can also be symmetric with respect to one or more axis in the pole plane through the center point of the pole, for example, the left and right halves, and the front and back halves are symmetrical.

According to the static magnetic field generating apparatus of the present invention, wherein the permanent magnetic source is arranged in rings according to the magnetic energy levels. The number of rings could be two, three or more. For example, when three rings are arranged, said permanent magnetic source is divided into three ring areas according to the magnetic energy levels, wherein the magnetic energy level of the external ring area is N3, the magnetic energy level of the middle ring area is N2, and the magnetic energy level of the inner ring area is N1, and N3>N>N1.

Another solution of the static magnetic field generating apparatus of the present invention is providing a plurality of magnetic conducting bolts or permanent magnetic bolts (11) symmetrically with respect to axes in the pole plane. Those adjusting bolts are mounted on one or a plurality of the parts of the pole plate (2), the permanent magnetic source (1), the first shimming ring (5) and the second shimming ring (6), so that the field strength of the static magnetic field is precisely adjusted.

In the prior art, the field strength at the edge of the magnet is usually lower than that at the center. Therefore, as a measure in the prior art, adding a first shimming ring (5) to the outer side of the gradient coil will increase the field strength at the edge. However, the inventor of the present application found that only using a first shimming ring (5) will not achieve satisfactory effect. Hence, as a part of the present invention, a second adjustable shimming ring (6) is added to the side of the first shimming ring (5) that faces the measured body and to the outer side of the gradient coil (7), and the fixing relation between the gradient coil and the transmitting coil is adjusted. For the volume production of the system, the manufacturing tolerances need to be considered.

According to the above-mentioned principle of the present invention, a shimming ring of different shape could be designed to replace the first shimming ring (5) and the second shimming ring (6).

In another aspect, in order to achieve shimming of higher homogeneity, the magnetic field profile has to be re-designed when designing the magnetic source assemblies of different magnetic energy levels. In this process, the factors that influence the field strength of the magnetic field should be considered, for example, manufacturing precision, deviation of the assembling position and even minor corner damage of the magnetic columns in the assembling process.

As a part of the present invention, for the adjusting bolts of ferro-magnetic or permanent magnetic material, screw threads could be made on many parts of the magnetic field generating apparatus, and the bolts are made by magnetic materials same to or different from the materials of said parts. Matching between the screw threads and the bolts is very important, because if they are too tight, a strong force

has to be applied to the screw rod during adjustment and thus causing deformation or even break of the bolts, but if they are in too loose contact, due to the vibration caused by the pulse magnetic force, the field strength will be made unstable and thus causing irregular changes of field strength.

According to the situations of the manufacturing, said additional shimming ring (6), permanent magnetic source (1) of different magnetic energy levels and adjusting bolts (11) of magnetic material of the present invention could be applied jointly. For instance, the shimming effect could be achieved by using a second shimming ring (6) in combination with permanent magnetic columns (1) of different magnetic energy levels, or by using the second shimming ring (6) in combination with fine adjustment by magnetic conducting bolts or permanent magnetic bolts (11). Meanwhile, the shimming effect could also be achieved by adopting permanent magnetic columns (1) of different magnetic energy levels to form magnetic field profile while combining the method of fine adjustment by magnetic bolts (11).

Or else, the shimming effect could also be achieved by adopting the second shimming ring (6), the magnetic source composed of permanent magnetic columns (1) of different magnetic energy levels and the fine adjustment by magnetic conducting bolts or permanent magnetic bolts (11) at the same time.

The present invention also discloses a method of adjusting the static magnetic field in magnetic resonance equipment, said magnetic resonance equipment comprises permanent magnetic source (1), C-type yoke or a multi-posts supporting structure that constitutes the magnetic path; the measured body is positioned in the space between the two opposite end faces of the permanent magnetic columns (1), wherein the said two opposite end faces are mirror symmetrical by the virtual plane between the two faces; Pole plates (2) are placed along the direction of the measured body on each of the opposite

end faces; the structure is symmetrical with respect to the virtual middle plane but for the illustration purpose, take the upper half for example, pole pieces (4) are employed beneath the aforementioned pole plate, a gradient coil(7) is employed beneath pole piece (4), an RF transmitting coil (8) is employed beneath gradient coil (7), a first shimming ring (5) is employed outside the gradient coil (7); each pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces, characterized in that: an additional second shimming ring (6) is employed on the external edge of the each of the first shimming rings (5), and the second shimming ring (6) is symmetrical to the above virtual plane, to uniform the static magnetic field in the space of the measured body; further, the permanent magnetic field source is composed of a plural groups of permanent magnetic columns of different magnetic energy levels, so that the magnetic energy level of the permanent magnetic columns further from the center of the pole plate is higher than that of the permanent magnetic columns nearer from the center of the pole plate, and thereby to improve the uniformity of the magnetic field; and more further, on the basis of the above-mentioned method, a plurality of magnetic conducing bolts or permanent magnetic bolts (11) are employed symmetrically along the end face axis of the permanent magnetic column (1) on the pole plate (2), the permanent magnetic column (1), the first shimming ring (5) and the second shimming ring (6), and by adjusting the positions of the said magnetic inducing bolts or permanent magnetic bolts (11), the field strength of the static magnetic field is adjusted.

Moreover, another method of adjusting the static magnetic field in MR equipment, said magnetic resonance equipment comprises permanent magnetic source (1), C-type yoke or a multi-posts supporting structure that constitutes the magnetic path. The measured body is positioned in the space between

the two opposite end faces of the permanent magnetic source (1), wherein the said two opposite end faces are mirror symmetrical to the virtual plane between the two faces; Pole plates (2) are placed on each of the opposite end faces; The structure is symmetrical with respect to the virtual middle plane; For the illustration purpose, take the upper half for example, pole pieces (4) are employed beneath the afore mentioned pole plate, a gradient coil is employed beneath pole piece (4), an RF transmitting coil (8) is employed beneath gradient coil (7), a first shimming ring (5) is employed outside the gradient coil (7); each pair of the pole plates (2), pole pieces (4), gradient coils (7), RF transmitting coils (8) and the first shimming rings (5) are substantially mirror symmetrical with respect to the virtual plane between the two opposite end faces; characterized in that : the permanent magnetic source (1) is composed of a plural groups of permanent magnetic columns of different magnetic energy levels, so that the magnetic energy level of the permanent magnetic columns further from the center of the pole plate is higher than that of the permanent magnetic columns close to the center of the pole plate, and thereby to improve the uniformity of the magnetic field, and meanwhile, a plurality of magnetic conducing bolts or permanent magnetic bolts (11) are employed symmetrically along the end face axis of the permanent magnetic source (1) on one or a plurality of parts in the said pole plate (2), permanent magnetic source (1), first shimming ring (5) and the second shimming ring (6), and by adjusting the positions of the said magnetic conducing bolts or permanent magnetic bolts (11), the field strength of the static magnetic field is precisely adjusted.

(4) Description of figures

The five figures of embodiments of the present invention further illustrate the principle of the present invention, wherein:

Fig. 1 shows the shimming rings on the upper and lower poles of the C-type magnet;
Fig. 2 shows the enlarged drawing of the part marked in a circle in Fig. 1;
Fig. 3 shows the method of adjusting field strength by using a plurality of magnetic conducting or permanent magnetic bolts;
Figs. 4 and 5 show the method of making the magnetic field more uniform by making different areas of the magnetic field to have different magnetic energy levels.

Fig. 1 shows the shimming rings of the upper and lower poles of the C-type magnet. In Fig. 1, component 9 is the press plate, component 10 is the magnetic field generating source, which comprises the permanent magnetic columns (1). A plurality of magnetic conducting or permanent magnetic bolts (11) which could move up and down are shown in the external edge of the magnetic field source in Fig. 1 so as to achieve the above-mentioned effect.

Fig. 2 is the enlarged drawing of the part marked in a circle in Fig. 1, wherein component 1 is the permanent magnetic source, component 2 is the pole plate, component 3 is the pole plate after cutting processing, component 4 is the pole plate, component 5 is the first shimming ring, component 6 is the second shimming ring with an adjusting means, component 7 is the gradient coil and component 8 is the RF emitting coil. It can be seen from Fig. 2 that a new shimming ring (6) is added in addition to the original shimming ring (5). In Fig. 2, the outer diameter of the upper shimming ring (5) is the same as that of the lower shimming ring (6). The inner diameter of shimming ring (6) is larger than that of the shimming ring (5), so that space that is smaller than the inner diameter of shimming ring (6) and under the shimming ring (5) could be used for fixing the gradient coil. The lower end face of the shimming ring (6) is not lower than the lower plane of the transmitting coil. Similarly, the two

shimming rings of the lower pole plate are located at the position that is corresponding to the position in the upper plate, and such design will not reduce the distances between the upper and lower pole plates as well as between the two shimming rings, i.e., the openness will not be affected. In Fig. 2, two dark black arrows that show movement horizontally and vertically respectively are used to indicate the shimming ring (6) and the bolts mounted on the first shimming ring (5) and the second shimming ring (6) can be adjusted in two directions.

Careful consideration on the size and position of the second shimming ring (6) will help to improve the magnetic field distribution at the edge and enhance the adjusting effect of the shimming, and meanwhile, the open space between the upper and lower poles will not be affected.

Fig. 4 shows another method of changing the uniformity of the field strength. Generally, in permanent magnet with field strength over 0.3T, the field strength at the edge of the pole plate thereof is weaker than that at the center of the pole plate. In order to make the magnetic field of the area between the two pole plates more uniform, the present invention puts forward a method of dividing the magnetic field generating source into several areas and magnets at different areas have different magnetic energy levels. As an example shown in Fig. 4, the several circular-shape or ring-shape areas on the pole plate of the present invention that are centered at the axis of the pole plate are made to have different magnetic energy levels, wherein the magnetic energy level in the center area is N1, the magnetic energy in the middle area is N2 and the magnetic energy level in the external area is N3 and $N1<N2<N3$. Also, as shown in Fig. 4, a plurality of magnets of different magnetic energy levels could be provided in the manner of being symmetrical along the vertical axis through the center of the pole plate.

Fig. 5 is a longitudinal section of the magnet, and the shadows of different gray levels indicate magnet objects of different magnetic energy levels, which are symmetrical along the center of the magnet. The magnetic energy level at the center area is lowest and magnets nearer the external edge have higher magnetic energy levels. Other magnetic energy levels combination forms could be derived on the basis of the principle of the present invention according to the non-uniform structure intentionally designed on the pole plate and the characteristics of the magnetic path. Magnetic energy level could be divided into a plurality of levels, and the ordering of the energy level is not limited to the manner of increase from the center to the outer edge, and adjustment could be made on the basis of the pole plates and the magnetic path structures of the devices.

In addition, as shown in Fig. 3, another method of uniforming the magnetic energy level of the present invention is to insert a plurality of magnetic bolts at the external edges of the pole plate and the press plate, and the uniformity of the field strength is adjusted by changing the magnetic path. As shown in Fig. 3 (and Fig. 1), these magnetic bolts could be arranged symmetrically. However, if the influence of the middle section connecting object of the C-type magnet on the field strength between the two poles or other multi-column plate structures are considered, these bolts could also be arranged in a non-symmetrical way. In the existence of tolerances of manufacturing and assembling of said magnetic resonance imaging equipment, the field strength of the diagnosing area could be adjusted by adjusting these bolts to some extent. The material of the bolts could be permanent magnetic material or ferromagnetic material and the diameters of the bolts could be either the same or different, but they are preferably the same. The bolts should be arranged symmetrically or near symmetrically, and the number of the bolts should be set according to the strength of the magnetic field and the practical structure, and too many bolts will make the

adjusting difficult. It is not difficult for those ordinarily skilled in the art to change and adjust those bolts according to the specific cases to achieve the shimming effect.

The operators could use one or a combination of the above-mentioned methods to achieve better shimming effect.

One advantage of the apparatus and method of the present invention lies in that the magnet made by the method of the present invention could have field strength higher than 0.3T with higher homogeneity in the scanning area satisfying the requirements. Therefore, the size of the apparatus could be reduced and the cost will be reduced. For example, the specifications of the magnet of 0.35T manufactured according to the present invention are as follows: the weight is less than 16 tons, the uniformity of the magnetic field in 36cm sphere is less than 40ppm; and the width of the patient gap is larger than 41cm and the stability of the static magnetic field is $<\pm$20Hz/10 minutes.

Another advantage of the apparatus and method of the present invention is that since the apparatus could be precisely designed and adjusted, most shimming works could be finished during the processing of manufacturing and assembling of in factory and it is unnecessary to carry out passive shimming at site and thus saves the time for installation.